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### (54) Apparatus for electrical stimulation of the gastrointestinal tract

(57) An apparatus for providing electrical stimulation of the gastrointestinal tract. The apparatus features an implantable pulse generator (3) which may be coupled to the gastric system through one or more medical electrical leads (4, 5). In the preferred embodiment the leads couple to the circular layer of the stomach.

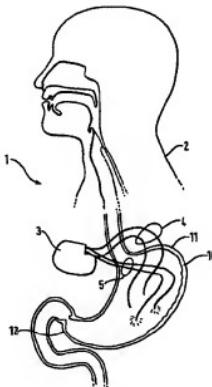


FIG. 1

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**Description**

[0001] The invention relates to treatment of gastrointestinal disorders using an apparatus for providing electrical stimulation of the gastrointestinal tract.

5 [0002] The gastrointestinal tract is responsible for an essential step in the digestive process, the reception of nutrition in the human body. An important element of the digestive process is peristalsis, the coordinated and self-regulated motor activity of the intestinal tract. Peristalsis is accomplished through a coordinated combination of electrical, chemical, neurological and hormonal mediation, as well as possibly other, as yet unknown, mechanisms.

10 [0003] Many diseases and maladies can affect the motor activity of the gastrointestinal tract, causing malfunction of the digestive process. Such diseases include diabetes mellitus, scleroderma, intestinal pseudo-obstruction, ileus, and gastroparesis.

[0004] Gastroparesis, for example, is a chronic gastric motility disorder in which there is delayed gastric emptying of solids and/or liquids. Symptoms of gastroparesis may range from early satiety and nausea in mild cases to chronic vomiting, dehydration, and nutritional compromise in severe cases. Diagnosis of gastroparesis is based on demonstration of delayed gastric emptying of a radio-labeled solid meal in the absence of mechanical obstruction. Gastroparesis may occur for a number of reasons. Approximately one third of patients with gastroparesis, however, have no identifiable underlying cause (often called idiopathic gastroparesis). Management of gastroparesis involves four areas: (1) prokinetic drugs, (2) antiemetic drugs, (3) nutritional support, and (4) surgical therapy (in a very small subset of patients.) Gastroparesis is often a chronic, relapsing condition; 80% of patients require maintenance antiemetic and prokinetic therapy and 20% require long-term nutritional supplementation. Other maladies such as tachygastria or bradygastria can also hinder coordinated muscular motor activity of the gastrointestinal tract, possibly resulting in either stasis or nausea or vomiting or a combination thereof.

15 [0005] The undesired effect of these conditions is a reduced ability or complete failure to efficiently propel intestinal contents down the digestive tract. This results in malabsorption of liquid or food by the absorbing mucosa of the intestinal tract. If this condition is not corrected, malnutrition or even starvation may occur. Moreover nausea or vomiting or both may also occur. Whereas some of these disease states can be corrected by medication or by simple surgery, in most cases treatment with drugs is not adequately effective, and surgery often has intolerable physiologic effects on the body.

20 [0006] Presently, however, there is no practically effective device or system to stimulate or intelligently alter the muscular contractions of smooth muscle and the gastrointestinal tract in particular. Therefore, there is a need in the art for a system to properly stimulate the gastrointestinal tract to thereby treat ineffective or absent electrical muscular activity of the gastrointestinal tract.

[0007] Patients suffering from gastroparesis have two symptoms which should be treated. First, many patients suffer from vomiting, nausea, bloating and abdominal pain. Second, many patients further suffer from motility disorders, i.e. the peristaltic contractions of the gastrointestinal organ is either inhibited or completely absent.

25 [0008] It is an object of the invention to provide an apparatus for treating patients having dysfunctional gastrointestinal muscle or disorders of smooth muscles elsewhere in the body.

[0009] This and other objects are provided by one or more of the embodiments described below.

30 [0010] According to one aspect, the present invention provides an apparatus for providing electrical stimulation to the gastrointestinal tract comprising: means for electrically coupling to the gastrointestinal tract; and a pulse generator coupled to the means for electrically coupling to the gastrointestinal tract, the pulse generator emitting a first type of electrical stimulation at a first rate and a second type of electrical stimulation at a second rate.

[0011] According to another aspect, the present invention provides an apparatus for providing electrical stimulation to the gastrointestinal tract comprising: means for sensing slow waves; means for sensing spike activity in a predefined

35 period following the sensing of slow waves; means for delivering a first type of pulse train stimulation; means for inhibiting the means for delivering a first type of pulse train stimulation when a slow wave is sensed by the means for sensing slow waves; means for delivery of a second type of pulse train stimulation; means for inhibiting the means for delivering a second type of pulse train; and stimulation when spike activity is sensed by the means for sensing spike activity.

40 [0012] In the preferred embodiment the leads couple to the circular layer of the stomach. The pulse generator preferably provides stimulation to the gastrointestinal organ with a first type of pulse train at a first rate to treat vomiting and with a second pulse train at a second rate to increase motility. In the preferred embodiment, as discussed below, the first type of pulse train is delivered at approximately 12 bpm while the second type of pulse train is delivered at a much slower rate, typically around 3 bpm. Through this stimulation, using two unique types of pulse trains at two distinct rates of delivery, both the symptoms of vomiting and lack of motility may be treated.

45 [0013] The above-described and other aspects of the present invention may be better understood and appreciated with reference to a detailed description of a specific embodiment of the invention, given by way of example only, when read in conjunction with the accompanying drawings, wherein:

- FIG. 1 depicts apparatus according to the invention implanted within a patient.  
 FIG. 2 depicts a detailed view of the stomach muscle showing the electrode of the lead implanted.  
 FIG. 3 depicts a plan view of a lead used with the apparatus.  
 FIG. 4 is a functional block diagram of the pulse generator.  
 5 FIG. 5 is an electrogastrogram of the gastrointestinal system.  
 FIG. 6 depicts the operation of a device according to the present invention while in an asynchronous mode, i.e. the stimulating pulse trains are provided regardless of the intrinsic activity of the gastrointestinal organ.  
 FIG. 7 depicts an alternative mode in which the device may operate.  
 FIG. 8 is a flow chart showing the operation of the device illustrated in FIG. 7.  
 10 FIG. 9 depicts an alternative embodiment of the present invention which operates in an inhibited mode.  
 FIG. 10 is a flow chart illustrating the operation of the device depicted in FIG. 9.  
 FIG. 11 depicts the operation of an alternative embodiment of the present invention.  
 FIG. 12, 13, and 14 depict flow charts of the various manners in which the device illustrated in FIG. 11 may operate.

15 [0014] The FIGS. are not necessarily to scale.

[0015] FIG. 1 shows a system 1 implanted in a patient 2. As seen, the system 1 comprises an implantable pulse generator 3 featuring two sets of leads 4, 5 which are coupled to the stomach 10. The first set of leads 4 provides stimulation to the stomach. The second set of leads 5 provides sensing of the gastroelectrical activity of the stomach 10 to the pulse generator 3. In the preferred embodiment, the pulse generator 3 is implanted within the patient 2. As such, the implantable pulse generator 3 features a hermetic enclosure, as is well known in the art. The leads used for both the first set 4 and the second set 5 may be any acceptable lead. In the preferred embodiment, the preferred leads are Medtronic Model No. 4300 intramuscular lead. Of course, other configurations of leads or lead systems may be used, including the use of from only a single lead, a single set of leads (i.e. two), or even the use of three or more sets of leads. Moreover, although shown as being coupled to the stomach it must be understood that the present invention may be used along or on any of the other structures and organs along the gastrointestinal tract, including the colon, small intestine, stomach or even the esophagus.

[0016] The first set of leads 4 are stimulation leads which conduct stimulation pulses from the pulse generator 3 to the stomach 10. First set of leads 4 are preferably implanted through the serosa at the area within the transition of the corpus and the antrum on the great curvature. Of course, other locations for first set of leads 4 may be used, such as in the fundus, caudad corpus as well as the orad or terminal antrum. The second set of leads 5 are sensing leads which conduct any gastroelectrical activities sensed in the stomach 10 to the pulse generator 3. Preferably the second set of leads 5 are positioned distally in the mid antrum also along the great curvature, although these leads may also be positioned in other locations.

[0017] FIG. 2 details the preferred positioning of an electrode of a lead within the various layers of the stomach. As seen, the stomach 10 has essentially seven layers of tissue. In the preferred embodiment, the electrode of each lead is positioned into the layers of the stomach muscle as shown. That is, the electrode is positioned such that it intersects both the longitudinal and circular layers. This is believed important by the inventor because in such a manner the electrode is able to also intersect the enteric nervous system of the stomach and be in close contact with the cells of Cajal. This is believed important as research has shown that intramuscular electrodes may effectively stimulate the stomach with less than one one-thousandths of the energy required for serosal electrodes. Of course, other types of electrodes or lead systems may be used, including those which contact only any one of each of the layers of the stomach organ, such as only the mucosa or only the serosa. Moreover, although in the preferred embodiment a pair of unipolar leads are used for stimulation and a second pair of unipolar leads are used for stimulation, other configurations of leads may be used, such as bipolar, tripolar, quadrupolar, as well as any other configuration suitable such as a unipolar lead and can.

[0018] FIG. 3 depicts a plan view of the preferred embodiment lead 15 used in the present invention. As seen, the lead 15 essentially has three sections, connector section 16, body section 17 and fixation section 18. Connector section 16 includes a connector pin 22 to electrically couple the lead 15 into the pulse generator. Any connector pin 22 as well known in the art may be used. Body section 17 includes an electrical conductor 19 surrounded by an electrical insulator 20. In the preferred embodiment electrical conductor 19 is a platinum iridium alloy and electrical insulator 20 is silicone. Of course, other biocompatible materials may also be used. As seen, at the distal end of the body section 17 is an electrode 25. In the preferred embodiment, electrode 25 is a polished platinum iridium alloy. Of course, other materials may likewise be used, such as a porous platinumized structure. In addition, the electrode 25 could further feature various pharmaceutical agents, such as dexamethasone sodium phosphate or betamethasone phosphate in order to minimize the inflammatory response of the tissue to the implanted lead 15. Other agents such as antibiotics may also be used. Located distal to the electrode 25 is the fixation section 18. As seen, fixation section 18 has essentially two piece parts, a suture 26 which is in turn coupled to a needle 27. Needle 27 is preferably curved. In an alternative embodiment the suture may feature a fixation coil as is well known in the art to cooperate with the body tissue after implantation to main-

tain the lead 15 in the position implanted. Of course, other fixation mechanisms may be used, such as fixation discs, as is well known in the art.

[0019] FIG. 4 depicts a functional block diagram of a gastrointestinal pulse generator according to the present invention. As seen, pulse generator 3 is enclosed by hermetic enclosure 40 to the electronics and battery while the device is implanted. Hermetic enclosure may consist of any suitable construction. Pulse generator 3 couples with two sets of leads 4, 5 which are, in turn, coupled to the stomach 10. The first set of leads 4 transmits stimulation pulses from pulse generator 3 to the stomach. The second set of leads 5 provides sensing of the gastroelectrical activity of the stomach 10 to the pulse generator 3. Although in the preferred embodiment the stimulating leads and sensing leads are separate leads, the present invention may also be employed using a combination of leads which both sense and stimulate.

[0020] As seen, the sensing leads 4 are coupled into a slow wave detection circuit 41. Slow wave detection circuit 41 includes a band pass amplifier, a slew rate converter and two threshold detectors. Essentially, such a slow wave detection circuit 41 is similar to those used in a cardiac pacemaker but with several important characteristics. First, the band pass amplifier has a much lower centre frequency, preferably of the order of 0.3Hz but anywhere between approximately 0.1 and 0.5 Hz may be used in the stomach. Of course, the present invention may be used in each of the various organs along the gastrointestinal tract so that the centre frequency may be varied accordingly. The slew rate converter operates in a manner well known in the art and generates a signal corresponding to the slew rate of the sensed electro-gastrogram. The threshold detectors operate in a manner well known in the art and generate output signals when the sensed input signal is above a threshold level. One threshold detector corresponds to the peak to peak amplitude of the sensed electro-gastrogram. The second threshold detector corresponds to the sensed slew rate.

[0021] Preferably, the slow wave detection circuit 41 must be able to detect input signals between approximately 30 microvolts and 10 millivolts which have a slew rate between approximately 100 microvolts per/second up to 10 volts per/second with a typical value of 100 millivolts per second. Such a range may be achieved using multiple steps which are controlled by the microprocessor 46 via the input line 46b-41d. To detect the slow wave, both threshold detectors should be coupled using a logical AND configuration. Thus, a signal should then be sent via the output line 41c-48a to the microprocessor 46. The slew rate detector may also include an interference detector specially designed to detect continuous interference, especially at any of the various mains frequencies of power distribution (e.g. 16-400 Hz) so that false sensing is avoided. In an alternative embodiment a second sense amplifier may be provided having a bandpass in the range of expected power field variations in various frequencies of power distribution (e.g. 16-400 Hz). At every cycle the presence of interference is detected. The time interval between approximately two detections is measured and if this time interval corresponds to any of the main frequencies of power distribution which is preprogrammed, then this detection is labeled as interference and the detection on the other amplifier will be simultaneously labeled also as interference detection and not as a valid slow wave.

[0022] The band pass amplifier in the detection circuit 41 should be blanked for a period after a sensed event has been received by the microprocessor 46 or just before and during a stimulation pulse is emitted by the output stage discussed below. Blanking may be accomplished through either a blanking switch which disconnects the amplifier from the electrodes or through a program performed in the microprocessor. The microprocessor 46 should also ignore sensed output signals during a period after a sensed or paced event. This is similar to a blanking circuit where sensed events during a blanking period do not affect the timing of the pulse generator. In the preferred embodiment, the blanking period for slow wave detection is of the order of between approximately 0.5 to 4.0 seconds.

[0023] Generally speaking, the blanking period decreases with increasing slow wave frequency. The blanking period algorithm is controlled by the microprocessor. The blanking period algorithm operates such that when the slow wave interval is shortened the blanking period is also shortened. This shortening may be performed in any manner, for example, in a linear fashion or in some other more complex monotonous fashion. After the blanking period, during a certain timing window, the microprocessor 46 is able to receive slow wave detection signals, which will not restart the pulse generator timing circuit, but will instead be interpreted as interference by the microprocessor 46. This timing window, the interference detection timing window, may be up to seven seconds in duration after the sensed or paced event, preferably it is 100 milliseconds. To be precise, the combined blanking period and interference detection windows are shortened. Shortening may occur in any manner desired, i.e. in a linear fashion between approximately a preset high or a preset low value or along a non-linear manner. The shortening of the combined blanking and interference detection interval will not occur once the combined blanking and interference detection window reaches a programmed value, such as 2.5 s. This combined blanking window may also be programmed to be turned off such that it does not change in response to sensed physiologic signals. In all circumstances, however, the interference detection window remains equal to at least 100 ms. For example, the rationale is that the typical main frequencies of power distribution are 50 Hz, 60 Hz, 400 Hz and 1633 Hz. The lower harmonic for 1633 Hz is 8 Hz which corresponds to an interval of 125 ms. Of course the exact length of time for each period may be programmed by the physician. Moreover, each of the periods may be further made to be automatically adjusted based on the sensed electrical activity.

[0024] As seen in FIG. 4, blanking switch 42 couples sensing electrodes 4 to amplifier 45 to detect high frequency spike activity. The operation of blanking switch 42 causes the amplifier 45 to be connected to the sensing electrodes 4.

once an intrinsic deflection or slow wave has been detected by slow wave detection circuit 41 or a stimulus has been emitted by output stage 47. Preferably, this occurs after a short delay. Blanking switch 42 is closed between approximately 0.5 to 2 seconds after these events and opens roughly 5 to 7 seconds later or at approximately 30% of the intrinsic event interval. As seen, the switch is controlled via the line 46e-42e.

- 5 [0025] The detection circuit for the high frequency spike activity detector consists of a bandpass amplifier having the centre frequency at approximately 300 Hz. As discussed above, however, the centre frequency will vary for different organs. The amplifier is followed by two threshold detectors, the first detector detects peak to peak amplitude while the second detector detects slew rate. Both detectors are coupled using a logical AND configuration. The detector pulses are counted, and the interval between pulses is measured. If the interval corresponds to the intervals of the mains frequencies of power distribution or any of their harmonics, i.e. 20 ms or 10 ms, they are rejected. If the number of pulses exceeds a pre-programmed value, then a contraction is indicated. The counter is provided to store in the memory the time of occurrence of the contraction. The number of pulses corresponding to each contraction may be counted and tallied to determine the strength of the contractions. In the present embodiment 3-5 pulses correspond to a weak contraction; 6-8 pulses correspond to a moderate contraction; 9 or more pulses correspond to a strong contraction. Each of these values, of course, may be programmed and the exact number of pulses will vary due to the implementation.

- 10 [0026] Also coupled to the sensing electrodes 4 is an AC current generator 43. This AC current generator 43 is part of a plethysmography circuit. Overall, the plethysmography circuit is present to provide a means for sensing mechanical activity of the underlying tissue. That is, whereas the spike activity in the electrogastrogram may be used to sense contraction, the contraction may also be sensed using the plethysmography circuit. Plethysmography circuit is comprised from AC current generator 43, amplifier, modulator and ADC converter 44 as well as a portion of the microprocessor 46. The AC current generator 43 is switched on via a signal from microprocessor 46 once a slow wave is detected or a pacing stimulus is emitted. It is switched off roughly 10 seconds after being switched on also from the same line or signal from the microprocessor 46. The AC current generator 43 amplitude and frequency are programmable via microprocessor 46. The frequency should be such it is not detected by amplifiers 41, 45, e.g., 1 kHz. If synchronous detection 25 by amplifier 41 occurs at the end of the blanking period, then the amplitude and/or the frequency of the AC current generator 43 is adjusted by the microprocessor 46 to avoid subsequent detection of the generated AC current.

- [0027] Turning now to the amplifier, the modulator and ADC converter 44, the AC voltage caused by the injection of AC current generator 43 is amplified and demodulated and converted in order to detect impedance changes caused by contractions of the underlying tissue. The ADC converter digitizes the amplitude of the demodulated signal. The digitized signal is transmitted via line 44c-46h to the microprocessor 46. The microprocessor 46 analyzes the signal pattern by comparing it with one or more templates to identify it as a contraction as well as to reject interference or signals generated by postural changes or vomiting. This template comparison is done synchronously to the detection of the slow wave. Line 46i-44d is used to control the amplifier and ADC from the microprocessor 46.

- 30 [0028] The microprocessor 46 handles all timings and data storage of the pulse generator and may be of any suitable design. In the preferred embodiment, a microprocessor 46 such as that used in the Thera® I series of Medtronic pacemakers is used. The description of the microprocessor 46 function is described in the section below which details the operation of the algorithm used in the present invention.

- [0029] Stimulation pulses are generated by the output stage 47. In the preferred embodiment, the output stage 47 generates pulse trains. It should be understood many types of pulse trains or stimulation pulses may be used including constant current or constant voltage outputs, or a mixture of both. The output pulses are transported to the gastrointestinal tissue via medical electrical leads 5 and thus to the stomach.

- 40 [0030] Turning again to the output stage 47, when an output pulse is to be delivered, its amplitude, pulse width and duration and frequencies are controlled via lines 46i-47a. If it is a burst of stimuli, the frequency and duration are controlled through the same line while a burst finished signal is sent to the microprocessor 46 via output line 47b-46k.

- 45 [0031] Programmability to the pulse generator 3 is achieved through receiver-demodulator 48 and transmitter 49. As seen, each of these devices is coupled to the microprocessor 46. The receiver-demodulator 48 and transmitter 49 are similar to those used in cardiac pacemakers.

- [0032] The basic parameter settings such as sensitivity (peak voltage or slew rate), refractory, blanking, output pulse amplitude, pulse width, escape interval and ratio of escape interval to a stimulation interval, are stored in the memory of the microprocessor 46. Default values are also stored. These values can be read from memory and sent to a receiver via the transmitter.

- 50 [0033] FIG. 5 shows an electrogastrogram of the stomach in a human. As seen, this intrinsic gastroelectric activity has two distinct components. The first component 501 is a low-frequency, rhythmic depolarization termed slow waves. Superimposed on the slow wave is a high frequency spike activity 502 which corresponds to mechanical contractions of the organ. In the human stomach slow waves are regular, omnipresent depolarizations at 3 cycles/min. (0.05 Hz) that commence high on the greater curvature of the stomach, in the region referred to as the pacemaker region, and propagate aborally, as depicted in FIG. 2.

[0034] The normal frequency range for the slow wave in the stomach is between approximately 2.7 - 3.4 bpm. In clin-

ical situations this value may vary anywhere between approximately 1-15 bpm. High frequency slow wave activity (called tachygastria) does not permit contraction of the stomach readily and may even results in a gastroparesis. In the presence of excessively slow or even absent slow waves (called bradygastria) motility is reduced.

[0035] Slow waves and the corresponding spike activity may become irregular or uncoupled or both, thereby preventing the appearance or organization of regular, normally propagated contractions that constitute normal motility. Contractions cannot occur without gastric electrical response activity which is in turn regulated by the electrical control activity. Any disruption in this delicate sequential order may lead to delayed gastric emptying. An example of such an occurrence is shown in complex 505.

[0036] The spike activity occurs incidentally for a few of the slow waves while the patient is in a fasting or non-eating condition. This is termed Migratory Motor Complex phase I. Immediately prior to a meal, typically 30 mins, MMC I changes into MMC II. During this phase the number of slow waves having spike activity increases. Once the meal or eating has begun and up to 120 mins after the meal each further slow wave also has a spike activity component. This condition is called MMC III.

[0037] As seen in this complex a slow wave 510 occurs which is not followed by any high frequency spike activity. The absence of such activity indicates there is no longer any peristaltic contraction which will occurs, i.e. gastric emptying is delayed.

[0038] FIG. 6 depicts the operation of the present invention while in an asynchronous mode, i.e. the stimulating pulse trains are provided regardless of the intrinsic activity of the gastrointestinal organ. As seen, the output channel of the device delivers a first set of low energy pulse trains 901-1 et seq. delivered at a frequency approximately four times the rate of normal slow waves (4 times 3bpm.) Low energy pulse trains preferably consist of a pulse train delivered at a rate of between approximately 7 - 27 bpm with 12 bpm preferred and consisting of two pulses, each pulse having an amplitude A, a pulselwidth PW and an inter pulse interval II. II may be anywhere between approximately 6 - 600 ms in length with 60 ms preferred, A is between approximately 1 - 50 millamps with 5 millamps preferred and pulselwidth is between approximately 3 - 1000 microseconds with 330 microseconds preferred. Moreover, although the pulse train consisting of two pulses is preferred, any number of pulses between approximately 1 - 100 may be used. As discussed above, the exact parameters selected depend not only on the organ to be stimulated but also upon the patients physiology as well as on the preference of the physician attending. As further seen in this FIG. the device also may deliver a high energy pulse train 902. As seen, the high energy pulse train is delivered approximately 3 bpm or 10% above the normal slow wave frequency times per minute. In the preferred embodiment the higher energy pulse train comprises a pulse train of between approximately 1-4 pulses. Each pulse may have an amplitude of between approximately 1 and 7 with 3 Volts preferred and a duration of between approximately 10 to 1000 milliseconds with 330 ms preferred. Each pulse is preferably separated by the delivered pulses in the train by an interval of 100 ms, although this may be anywhere between approximately 120 and 10 ms. In the preferred embodiment the device permits the physician to select any of the above parameters. These parameters are also selected according to the particular organ treated. As seen, this embodiment operates without regard to the underlying activity of the gastrointestinal organ. Thus the various slow waves which occur along the EGG 903-1 et seq. occur and no corresponding activity, simultaneously, is caused to occur along the output channel. As seen, slow waves 903-1, -2 and -3 differ from the slow waves of 903-4 and 903-5. In particular, these later slow waves feature high frequency spike activity which is seen in the segments 903-41 and 903-51 respectively. As discussed above these segments indicate a peristaltic contraction in the gastrointestinal organ. Essentially, the present invention provides low energy pulse trains to regularize intrinsic slow wave activity along with higher energy pulse trains to elicit spike activity, i.e. to regularize motility disorders.

[0039] FIG. 7 depicts an alternative mode in which the device may operate. As seen, the output channel of the device delivers lower amplitude pulse trains 901-1 et seq. The sensing of a slow wave 903-1 causes the device of this embodiment to be triggered and emit a higher energy pulse train 902-1. Once the higher energy pulse train is delivered the device continues to deliver a series of lower energy pulse trains 901-4, -5 and -6. The sensing of slow wave 903-2 again causes the delivery of a higher energy pulse train 902-1. The lower energy and higher energy pulse trains delivered in this mode of the device are similar to that already detailed above.

[0040] FIG. 8 is a flow chart showing the operation of the device illustrated in FIG. 7. As seen in step 100, the device determines whether a slow wave has been sensed. If no slow wave is sensed, the device continues in a sense mode whereby it continues to sense for any slow waves. Of course, the particular range of signals which would be sensed as a slow wave is programmable, and depends in part, upon the lead used as well as the location in which the lead is implanted within the gastrointestinal tract. If a slow wave is sensed, the device proceeds to block 102 in which it outputs a higher energy pulse train. As described above the output of this higher energy pulse train essentially is performed to elicit spike activity, i.e. to regularize motility within the stimulating portions of the gastrointestinal tract. Higher energy pulse trains may have an amplitude, frequency and duration as already described above. Next, the device turns to step 104 and outputs a lower energy pulse train or trains. As described above, these lower energy pulse trains are delivered to regularize intrinsic slow wave activity, thereby treating patient symptoms of nausea or vomiting, or both. A number of pulse trains, as well as any of their characteristics, e.g. amplitude, pulse duration, etc. may be set according to that

already described above. Once the lower energy pulse train or trains have been set the device resets itself, returning again to step 100. In such a manner the device may operate to deliver electrical stimulation triggered by the sensing of slow wave activity.

[0041] FIG. 9 depicts an alternative embodiment of the present invention which operates in an inhibited mode. As seen, the device continuously delivers the lower energy pulse train 901-1 et seq. The initiation of the delivery of lower energy pulse trains 901-1, -2 and -3 would open up the 902 timing window which upon expiring causes the delivery of higher energy pulse train 902-1. As seen, higher energy pulse train 902-1 evokes a slow wave 903-1 in the gastrointestinal organ. This slow wave, moreover, features a high frequency spike activity illustrated as component 903-11. As discussed above, this indicates peristaltic contraction is occurring. As seen, once the higher energy pulse train 902-1 is delivered the 901 timing window is begun which, upon expiration, causes the delivery of lower energy pulse trains 901-4, -5 and -6. When this delivery is begun another 902 timing window is again started, which, upon expiration, would cause the delivery of a higher energy pulse train. As seen, however, because the slow wave is sensed in the EGG this timing window is terminated, the delivery of a high energy pulse train is inhibited and, instead, a timing window is begun upon which the expiration of a low energy pulse train series will be scheduled 901-7, -8 and -9. The delivery of slow wave 901-7 again starts a timing window for the delivery of high energy pulse trains. As seen, when this timing window expires high energy pulse train 902-2 is delivered which thereby causes a corresponding slow wave 903-3 to be propagated within the EGG.

[0042] FIG. 10 is a flow chart illustrating the operation of the device depicted in FIG. 9. As seen in block 106, the device senses whether slow wave activity is occurring. As described above, signals which would be characterised as slow wave activity may be programmed. If no slow wave activity is sensed the device proceeds to block 108 and delivers lower energy pulse train or trains. The particular stimulating portion used to stimulate the pulse train or trains is programmable and is within the parameters as described above. Once the lower energy pulse train is delivered in block 108 the device recycles again and returns to block 106. If slow waves are sensed in block 106, then the device proceeds to block 110. In block 110 the device determines whether any spike activity is sensed. As discussed above, spike activity comprises high frequency signals which are part of or immediately follow a slow wave. Of course, the exact type of signal which may be sensed as spike activity is programmable. If spike activity is sensed, then the device recycles and proceeds back to block 106 in which it determines whether slow waves are present. If no spike activity is detected in block 110, then the device proceeds to block 112 and delivers a lower energy pulse train or trains. As discussed above, these lower energy pulse train or trains are delivered to elicit spike activity, i.e., to regularize motility within the area of the gastrointestinal tract which is stimulated. Once such higher energy pulse train is delivered the device again recycles back to block 106. In such a manner the device may be seen to operate such that the detection of either a slow wave or spike activity within a slow wave causes the device to inhibit the lower energy pulse train or the higher energy pulse train respectively.

[0043] FIG. 11 depicts the operation of an alternative embodiment of the present invention. In particular, in this embodiment the higher energy pulse trains are only delivered within a period corresponding to a meal time of the patient. As discussed below the sensing of meal time may be either performed by the device itself or may be patient activated. As seen, the device continues to emit low energy pulse trains 901-1 et seq. These pulse trains are delivered while slow wave activity occurs along the EGG 902-1, -2, -3 and -4. Upon the initiation of a meal time 910 the operation of the device changes and the sensed EGG changes. In particular, during a meal a slow wave includes a high frequency spike activity component. This component indicates that peristaltic contractions of the organ are occurring. As discussed above, when there are no contents within the stomach slow waves occur but these do not cause peristaltic contractions to likewise occur which is before, during or after a meal (referred to generally, herein, as meal time). The slow wave morphology changes to include high frequency spike activity when peristaltic contractions occur. Thus, during meal time, healthy individuals typically have high frequency spike activity within their slow waves. In healthy individuals this indicates peristaltic contractions are occurring. As discussed above, in some patients, the high frequency spike activity occurs even though peristaltic contractions do not. In the present invention this high frequency spike activity may be sensed to cause the delivery of high energy pulses 903-1 and 903-2. As seen, each of these pulse trains evokes a corresponding slow wave 902-5 and 902-6 respectively having high frequency spike activity 902-51 and 902-61 respectively. Upon the end of meal time designated as 920 the delivery of high energy pulse trains is inhibited and only a series of low energy pulse trains is delivered. Thus as seen, in this embodiment, high energy pulse trains are only delivered to cause a contractile activity during a meal time. Moreover, at all other times low energy pulse trains are delivered.

[0044] FIGS. 11, 12 and 13 depict flow charts of the various manners in which the device illustrated in FIG. 11 may operate. FIG. 11 discloses the operation of a device which senses the migrating motor complex before a higher energy pulse train is delivered. FIG. 12 depicts the operation of a device which senses the presence of food or liquid in the stomach before high energy pulse trains are delivered. Finally, FIG. 13 depicts the operation of a device which is patient controlled, i.e. the patient indicates to the device when meal time begins.

[0045] As discussed above, the device provides both lower energy and higher energy pulse train therapy to, either alone or simultaneously, treat the absence or irregular slow wave activity as well as the absence of corresponding spike

activity. For the patient the device thus provides treatment to both vomiting and nausea as well as motility disorders within the area of the gastrointestinal tract to be stimulated. The device may be operated using either a patient activation scheme such as a magnet-reed switch, ultrasound or infra red links, mechanical activation such as tapping on the device, or a hand-held patient programmer. As already discussed above, the device may further be activated through a timer by detection of contents within the stomach using mechanics. Moreover, although a single set of electrodes is shown as being used for sensing and stimulating the system, the present invention may simply use two sets of electrodes, one for stimulating and one for sensing. Moreover, the system could still further feature a third set of electrodes, one being used for sensing, the second set being used for the delivery of lower energy pulse trains while the third set could be used for the delivery of higher energy pulse trains.

[0046] Thus, as seen, the present invention provides an apparatus for treating two disorders of the gastrointestinal tract. Namely, the disorders treated are nausea and vomiting as well as motility disorders. The device provides this treatment by both sensing the underlying activity in the gastrointestinal tract as well as stimulating any response to this sensed activity. The device senses for both slow waves as well as spike activity. In response to the sensed signals, the device either delivers low energy pulse trains or high energy pulse trains, or both. A summary of the therapy matrix delivered by the present invention is shown below.

	Sense		Stimulation	
	Slow Wave	Spike Activity	Low Energy Pulse Train	High Energy Pulse Train
20	Present	Present	Inhibit	Inhibit
	Absent	Absent	Stimulate	Stimulate
25	Present	Absent	Inhibit	Stimulate
	Absent	Present	Stimulate	Inhibit

### Claims

- 30 1. An apparatus for providing electrical stimulation to the gastrointestinal tract comprising:  
 means (4, 5) for electrically coupling to the gastrointestinal tract; and  
 a pulse generator (3) coupled to the means for electrically coupling to the gastrointestinal tract, the pulse generator (3) emitting a first type of electrical stimulation at a first rate and a second type of electrical stimulation at a second rate.
2. The apparatus according to claim 1 wherein the first type of electrical stimulation is a first type of pulse trains and wherein the second type of electrical stimulation is a second type of pulse trains.
- 40 3. The apparatus according to claim 2 wherein the first type of pulse train is an asynchronous stimulation pulse train.
4. The apparatus according to claim 3 wherein the asynchronous stimulation pulse trains have at least two pulses, the two pulses having an interpulse interval of between 6 - 600 ms, an amplitude of between 1 - 50 millamps and pulselwidth between 3 - 1000 microseconds.
- 45 5. The apparatus according to claim 2, the first pulse train having a first section and a second section, the first section having a first section frequency, the second section having a second section frequency.
6. The apparatus according to claim 5 wherein the first section frequency is greater than the second section frequency.
- 50 7. The apparatus according to any of claims 2 to 6 wherein the first pulse train has a first amplitude, the second pulse train has a second amplitude.
8. The apparatus according to claim 6 wherein the first amplitude is less than the second amplitude.
- 55 9. The apparatus according to any preceding claim, further comprising:

- a sensor (41) for sensing intrinsic gastrointestinal electrical activity between the frequency of 100 - 300 Hz, the sensor coupled to the means for electrically coupling to the gastrointestinal tract, the sensor emitting an intrinsic gastrointestinal electrical activity signal upon the sensing of intrinsic gastrointestinal electrical activity between approximately the frequency of 100 - 300 Hz; and wherein
- 5           the pulse generator (3) emits a first type of stimulation pulse trains at a first rate, and emits a second type of stimulation pulse trains at a second rate in response to the intrinsic gastrointestinal electrical activity signal.
- 10          10. The apparatus according to claim 9 further comprising means (46) for switching the pulse generator (3) from emitting a first type of stimulation pulse trains at a first rate to emitting a second type of stimulation pulse trains at a second rate, the switching means coupled to the pulse generator and further coupled to the sensor (41).
11. The apparatus according to any of claims 1 to 8 comprising:
- 15          a sensor for sensing the presence of food or liquids within a first area of the gastrointestinal tract, the sensor emitting a mealtime signal upon the sensing of the presence of food or liquids within the first area of the gastrointestinal tract; and wherein
- 20          the pulse generator (3) emits a first type of stimulation pulse train at a first rate, and emits a second type of stimulation pulse train at a second rate in response to the mealtime signal.
- 25          12. An apparatus for providing electrical stimulation to the gastrointestinal tract comprising:
- means (41) for sensing slow waves;
- means (45) for sensing spike activity in a predefined period following the sensing of slow waves;
- means (4) for delivering a first type of pulse train stimulation;
- 25          means (46) for inhibiting the means for delivering a first type of pulse train stimulation when a slow wave is sensed by the means (41) for sensing slow waves;
- means (5) for delivery a second type of pulse train stimulation;
- means (46) for inhibiting the means for delivering a second type of pulse train; and stimulation when spike activity is sensed by the means (45) for sensing spike activity.
- 30          13. The apparatus according to claim 11 or 12 wherein the first type of pulse train is a high energy pulse train.
14. The apparatus according to claim 13 wherein the high energy pulse train comprises at least one pulse.
- 35          15. The apparatus according to claim 14 wherein the at least one pulse has an amplitude between 1 and 7 Volts.
16. The apparatus according to claim 14 wherein the high energy pulse train comprises a series of at least two pulses.
- 40          17. The apparatus according to claim 16 wherein the at least two pulses have an amplitude between approximately 1 - 50 millamps and pulsedwidth between approximately 3 - 1000 microseconds.
18. The apparatus according to any of claims 11 to 17 wherein the second type is a low energy pulse train delivered at a rate of between approximately 7 - 27 bpm.
- 45          19. The apparatus according to claim 18 wherein the low energy pulse train comprises a series of at least two pulses.
20. The apparatus according to claim 17 wherein the two pulses of the low energy pulse train have an interpulse interval between approximately 6 - 600 ms.
- 50          21. The apparatus according to claim 19 or 20 wherein the two pulses of the low energy pulse train have an amplitude between approximately 1 - 50 millamps.
22. The apparatus according to claim 19, 20 or 21 wherein the two pulses of the low energy pulse train have a pulsedwidth between approximately 3 - 1000 microseconds.

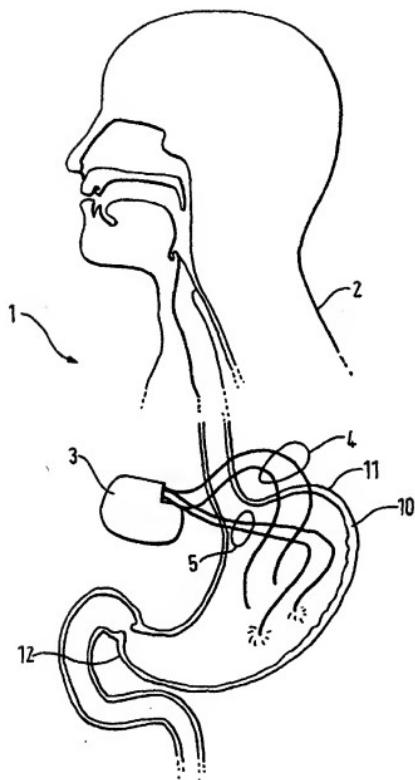


FIG. 1

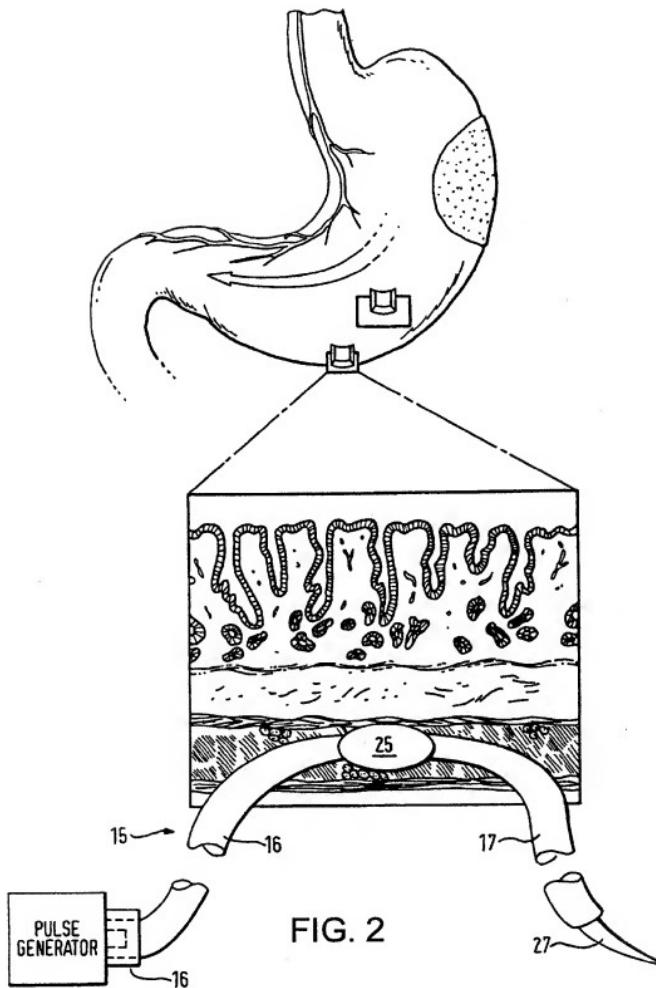


FIG. 2

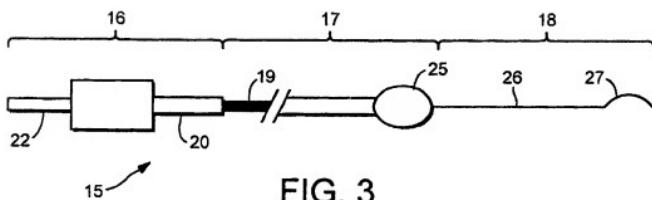


FIG. 3



FIG. 5

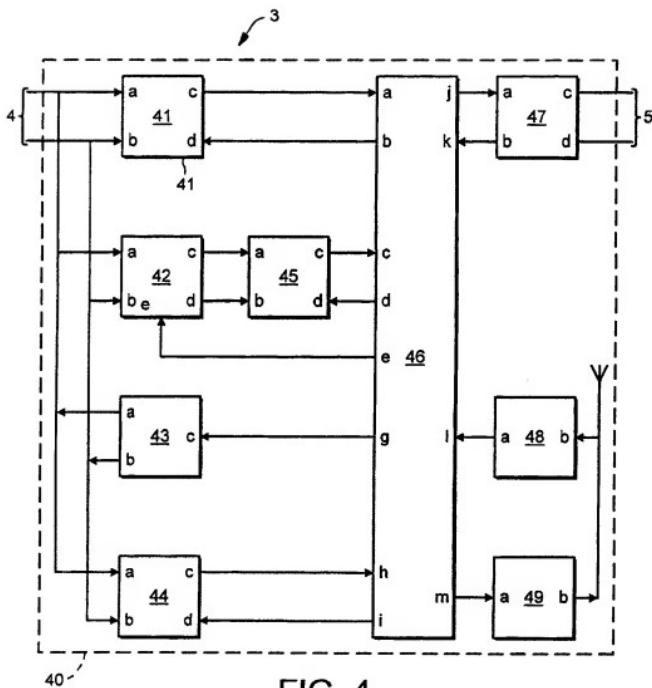


FIG. 4

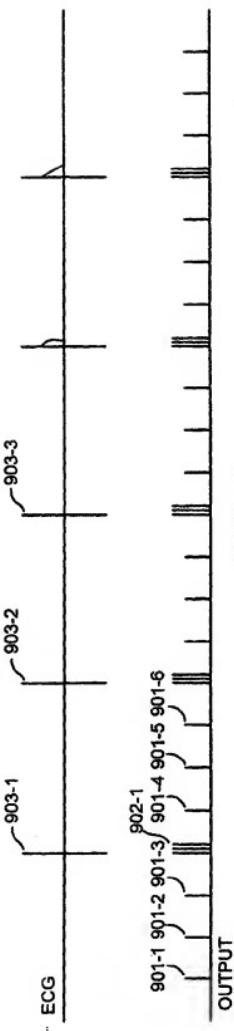


FIG. 6

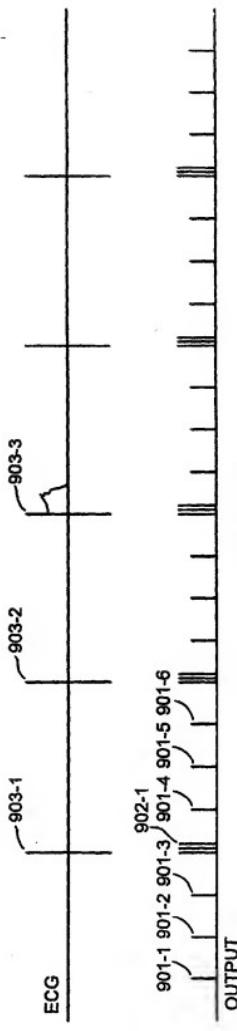


FIG. 7

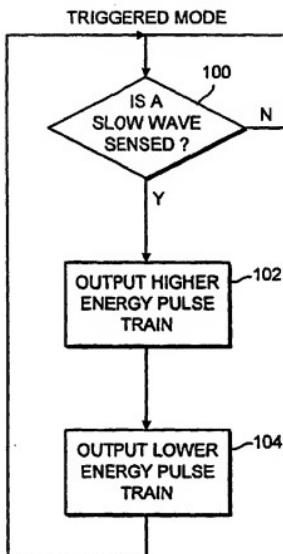


FIG. 8

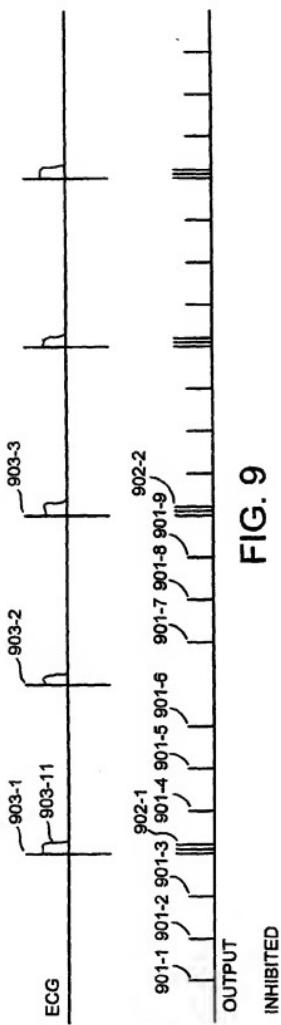


FIG. 9

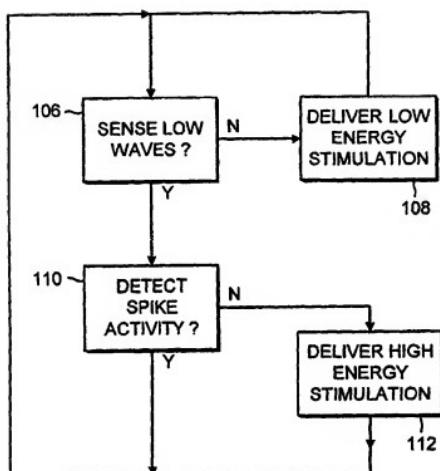


FIG. 10

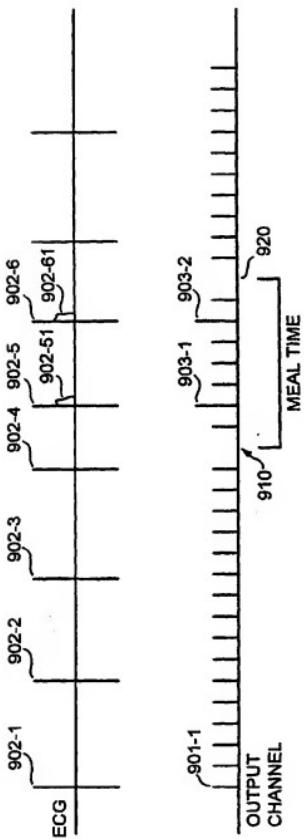


FIG. 11

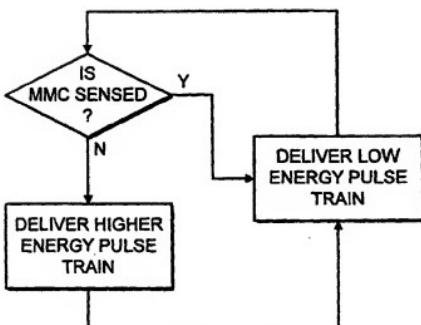


FIG. 12

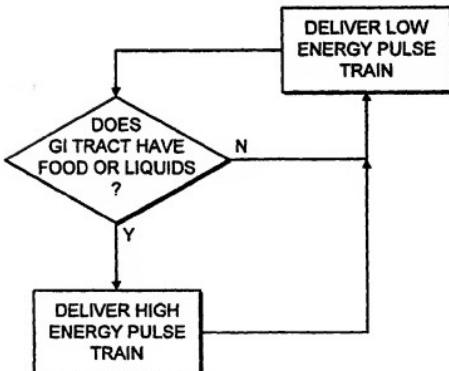


FIG. 13

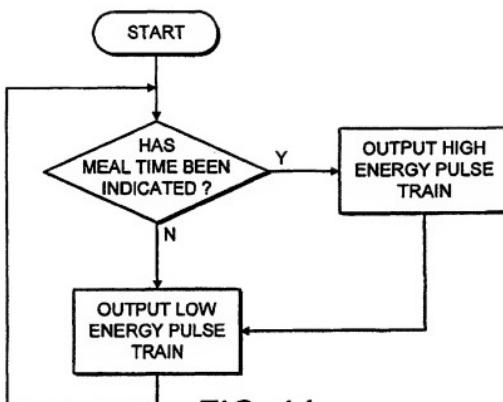


FIG. 14



European Patent  
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EUROPEAN SEARCH REPORT

Application Number  
EP 98 31 0233

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Place of search		Date of completion of the search	Examiner
THE HAGUE		18 March 1999	Allen, E
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